BROWSING REVERSIBLE NEIGHBORHOOD RELATIONS IN LINKED DATA ON MOBILE DEVICES

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Keywords: Semantic Web, Linked Data, Mobile Interaction, Mobile Computing, Human-computer Interaction, Human-computer Interfaces.

Abstract: Within the manufacturing and process industries pervasive computing is still less prominent than in other areas. This is mainly due to the lack of mobile solutions that are adapted to the special requirements for industrial tasks. This paper presents a novel mobile application for navigation in Linked Data. It follows the principle of limited purpose applications: support a single task and be good at it. First, we introduce a data model for representing reversible neighborhood relations in Linked Data. Second, we provide a human computer-interface for mobile devices that hides the complexity of the Linked Data Cloud. It allows browsing of reversible neighborhood relations such as industrial Piping & Instrumentation Diagrams and can be generalized to support arbitrary predecessor-successor networks. Third, we discuss our concept in respect to a real life example of a maintenance task in a large industrial plant.

1 INTRODUCTION

In recent years, the boundaries between office and field work have been dissolving and fewer people spend their whole workday at a single desk. Consequently, mobile devices are becoming increasingly important and increasingly pervasive (Pousttchi and Thurnher, 2007). At the same time, another development takes place: Innovation cycles are rapidly shortening while the pressure to create new products continues to increase. Enterprises try to face these challenges by concentrating on their core competencies and entering short-term cooperations with complementing companies (Schenker, 2010; AT&T Knowledge Ventures, 2008). Through their agility, these *virtual companies* have substantial competitive advantages over monolithic enterprises (Heck and Vervest, 2007).

Within these new organizational entities arises the need to share business and engineering information. One solution to this problem of data interoperability is Linked Data (Graube et al., 2011). Information to be shared is exported to the Linked Data Cloud and supplemented by unifying ontologies. In our paper we focus on mobile interfaces to this new information space in industrial working environments.

To fully exploit the potential of mobile devices in business and industrial applications, custom solutions

with a high degree of usability are needed. When good mobile tools are available, e.g. on-site working can lead to higher precision and quality of manufacturing (Viehland and Yang, 2007). However, engineering processes, shop floor maintenance and other industrial core tasks have rarely been integrated into previously suggested approaches to the aforementioned challenges (Urbas, 2010).

The goal of this paper is to present a mobile application that is suitable for engineering & maintenance tasks based on integrating technologies such as Linked Data, OWL & SPARQL. The *Semantic Neighborhood Browser* is meant to be part of a larger set of limited purpose applications supporting engineers and maintenance personnel (Urbas et al., 2011). It is optimized for usage in industrial environments that require adapted input patterns (Krausman and Nussbaum, 2007) and can be adapted to make arbitrary reversible Linked Data relations accessible to the user. All used data is available from planning and control systems and does not need additional manual curation.

The rest of the paper is structured as follows. First we provide a brief overview of the related work followed by an example scenario for the *Semantic Neighborhood Browser*. Then we describe our technical and theoretical approach. In the next section we describe the implementation and elaborate on possi-

ble use cases. The paper is completed by a discussion of features and open issues. Eventually, we give some concluding remarks and an outlook.

2 RELATED WORK

There are several established Linked Data browsers such as *RelFinder* (Heim et al., 2010), *Disco* (Bizer and Gauß, 2007) or *Tabulator* (Berners-Lee et al., 2008), among others (W3C, 2011). They mainly address end users who know how to interpret Linked Data and/or RDF. This knowledge is necessary because the browsers act directly on the RDF representation of the data.

Recognizing the general need for presenting RDF content to non-technical users and wanting to promote the exchange of presentation knowledge Pietriga et al., 2006 have designed *Fresnel* as a browser-independent vocabulary of core RDF display concepts. *Fresnel* is the basis for server-side applications such as *Marbles* (Bizer, 2009) or browsers such as *LENA* (Franz et al., 2010). Fresnel is not yet used in the proposed application but is a promising technology that may be incorporated in a later version.

The mentioned approaches call for large desktop displays and are designed with the WIMP-Pattern[1] in mind. Thus, these concepts may not be transferred directly to mobile devices.

DBpedia Mobile (Becker and Bizer, 2008), is a location-centric DBpedia client application for mobile devices consisting of a map view, the *Marbles Linked Data Browser* and a GPS-enabled launcher application. Sonntag and Heim, 2007, try to map RDF graphs directly towards appropriate multimedia visualizations to allow for semantic navigation within the football domain. An optimal graph layout is computed on the server-side, the mobile device works on an XML representation. While the implementation is a promising approach, the authors concentrate on natural language processing and consumer needs, rather than on industrial requirements. Further, *Ontowiki Mobile* (Ermilov et al., 2011) is a general browser for hierarchical and faceted browsing with conflict resolution for RDF content. On Android, *Sparql Droid* (Read, 2011) can be used for exploring RDF data.

We argue that not another general purpose browser for semantic data is needed. Instead, we follow the paradigm of single purpose applications and apply it to Linked Data. By limiting the scope to a single purpose, we enable users to leverage the power of semantic data sources by hiding their complexity. An

implementation like ours which is is based on a real scenario that illustrates the potential of Linked Data in industrial environments has not been available before.

3 EXAMPLE SCENARIO

To illustrate a typical application for the solution presented in this paper we provide a short scenario in this section. We introduce a persona called Wolfgang and follow him throughout an exemplary workday:

Wolfgang is 30 years old and works as a shift supervisor in a chemical plant. He has wide experience in his field because he has worked at this plant for more than five years. The plant consists of a multitude of basins, reactors, valves, pipes, etc. Protective garment such has heavy gloves, helmet and boots are obligatory in such a hazardous working environment. Just as every other morning, Wolfgang heads out to carry out his daily maintenance course through the facility. He will have to verify the operational reliability of various devices, calibrate equipment, take samples and complete similar tasks. He leaves the heavy briefcase containing the P&IDs[2] in his office. His maintenance routine is prescribed by the corporate regulations and helps to prevent failures or deviation of quality, as well as to conform with accepted standards.

When Wolfgang reaches a reactor in which several liquids are mixed by a stirrer, he realizes that it does not have the required fill level. Before filing a report, he decides to check the connected valves which control the inflow. He takes out his ruggedized Android tablet and scans the RFID tag embedded in the reactor basin. On the screen he now sees the *Semantic Neighborhood Browser* centered on the equipment under observation. In a large plant, devices can be far away from each other and hard to locate. Without ever taking off his gloves, Wolfgang navigates to the connected valves, displays their ID-number, verifies their location and reviews their specification. Having this information at hand, it is no problem for him to locate and check all connected valves for failure.

4 APPROACH

In our approach, we abstract from the real life challenge of navigation in a neighborhood environment to a graph-theoretical problem. The information flow for our approach can be seen in Figure 1.

The Linked Data principles (Berners-Lee, 2006)

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[1]Window, Icon, Menu, Pointer.

[2]Piping & Instrumentation Diagram.

allow an easy adaption and extension of the data as well as connections to other Linked Data information clouds without much effort. By following these principles the infrastructure of the *Semantic Neighborhood Browser* has been kept as generic as possible: All required data was aggregated as Linked Data in an external information cloud. There, the information was modeled with the help of RDF[3] as a semantic network consisting of triples. Each triple connects a subject node via a predicate arc to an object node.

Most of the data in industrial companies is stored as structured information in form of SQL databases, spreadsheets, XML files or proprietary databases. This data was automatically transformed to RDF using a converter with domain specific knowledge expressed by an ontology. The RDF model is stored in a triple store, an optimized database for semantic triples. The server hosting the data provides a SPARQL[4] endpoint. This allows powerful queries on graph patterns as well as inserting new triples in the triple store.
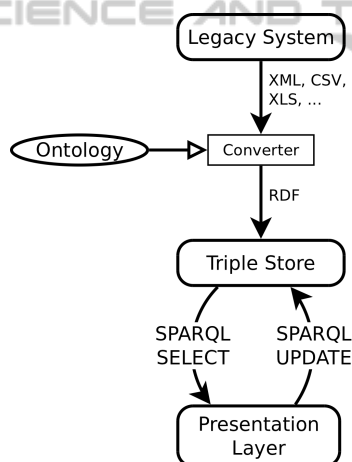

Figure 1: Flow of information.

5 IMPLEMENTATION

5.1 Hardware Platform

A 7″ HTC Flyer tablet with Android 2.3.4 was used to evaluate our application. The *Semantic Neighborhood Browser* is adaptive to screen size and is also well usable on 5.3″ or 10″ displays.

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[3]Resource Description Framework: http://www.w3.org/TR/rdf-primer/

[4]SPARQL Query Language for RDF: http://www.w3.org/TR/rdf-sparql-query/

5.2 Development Framework

The *Semantic Neighborhood Browser* was implemented using a combination of the cross-platform development framework *Qt*[5] and Semantic Web technologies.

The mobile application itself was developed using *Qt Quick*[6], a declarative language for rapid UI development. To query the SPARQL endpoint we made use of *QSparql*[7], a SPARQL library for Qt, that is currently in development. Since Android is not an officially supported platform for Qt, we took advantage of the *Necessitas* project[8], which is a community supported effort to port the *Qt* framework to Android and is based on *Qt Lighthouse*[9].

On the server side, we use an instance of the *Virtuoso Linked Data Server*[10] to hold the RDF data, to provide the SPARQL endpoint and to allow automatic creation of reverse links.

5.3 Use Case Example: Flow of Matter

5.3.1 Data Model

To illustrate the way the *Semantic Neighborhood Browser* works, we will give a short example showing how to navigate along a product stream in a chemical plant. In the example given in this paper, the data comes from a small batch plant used for educational purposes. The plant consists of some tanks, reactors, pipes, pumps and valves. These equipments allow to mix, heat and stir liquids from three reactant tanks in two reactors. The products can then be used for another reaction in the other tanks or filled into product tanks.

The whole plant was engineered in Comos[11], a Computer-Aided-Engineering (CAE) system. It provides a model of the plant equipment with all attributes and connections. Ab excerpt of the P&ID can be seen in figure 2. The relevant parts for the given scenario have been printed in bold. The reactor *R001* is located in the center of the figure, it can be filled

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[5]Nokia Qt: http://qt.nokia.com

[6]Qt UI Creation Kit: http://qt.nokia.com/qtquick

[7]QSparql project: http://maemo.gitorious.org/maemo-af/qsparql

[8]Necessitas: http://http://sourceforge.net/p/necessitas

[9]Qt Lighthouse: http://labs.qt.nokia.com/2011/05/31/lighthouse-has-grown-up-now/

[10]OpenLink Software Virtuoso: http://virtuoso.openlinksw.com/linked-data/

[11]Comos is a plant engineering software by SIEMENS: http://www.automation.siemens.com/mcms/plant-engineering-software/en/Pages/
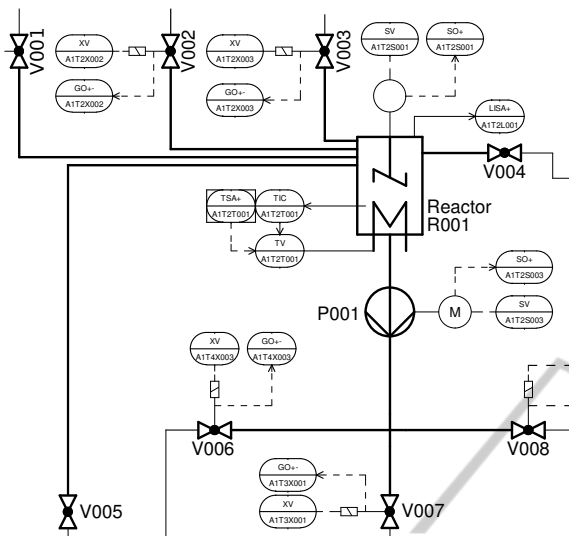
Figure 2: Detail of the piping & instrumentation diagram used in the example.

from three reactant tanks via the valves *V001*, *V002* and *V003*. The output of the reactor is connected to pump *P001* which delivers the product to the valves *V006*, *V007*, from where it flows to the product tanks and to valve *V008*. Reactor *R001* can also be filled from a purging tank (*V005*) or another source (*V004*).

The engineering data is exported from Comos to an XML format. This data is transformed to RDF using a Maintenance Structure Ontology (labeled *mso*) which describes the structure of the plant regarding the product flow. The namespace *sce* is used to describe the instances of the actual devices in the plant. The concepts for the different types of equipments are expressed as *mso:Valve*, *mso:Reactor* and *mso:Pump* which hold common attributes like *mso:rfid* and *mso:plantID* as well as type specific attributes (such as *mso:capacity* for tanks). The predicate for a directed flow connection from one equipment to another is *mso:connectedTo*.

The predicate *mso:connectedTo* is the one that defines neighborhood in our case.

The parts of the RDF model which belong to the described excerpt of the plant are shown in figure 3 in a serialized Turtle[12] format. This serialization is already human-readable, however, a graph visualization is provided in figure 4. It allows a better overview and a direct comparison to the P&ID in figure 2.

5.3.2 Example Navigation

After scanning the RFID tag attached to the device of interest, the *Semantic Neighborhood Browser* starts at

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[12]Turtle - Terse RDF Triple Language: http://www.w3.org/TeamSubmission/turtle/

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sce:V001 rdf:type mso:Valve .
sce:V002 rdf:type mso:Valve .
 ...
sce:V008 rdf:type mso:Valve .
sce:R001 rdf:type mso:Reactor .
sce:P001 rdf:type mso:Pump .

sce:V001 mso:connectedTo sce:R001 .
sce:V002 mso:connectedTo sce:R001 .
sce:V003 mso:connectedTo sce:R001 .
sce:V004 mso:connectedTo sce:R001 .
sce:V005 mso:connectedTo sce:R001 .
sce:R001 mso:connectedTo sce:P001 .
sce:P001 mso:connectedTo sce:V006 .
sce:P001 mso:connectedTo sce:V007 .
sce:P001 mso:connectedTo sce:V008 .
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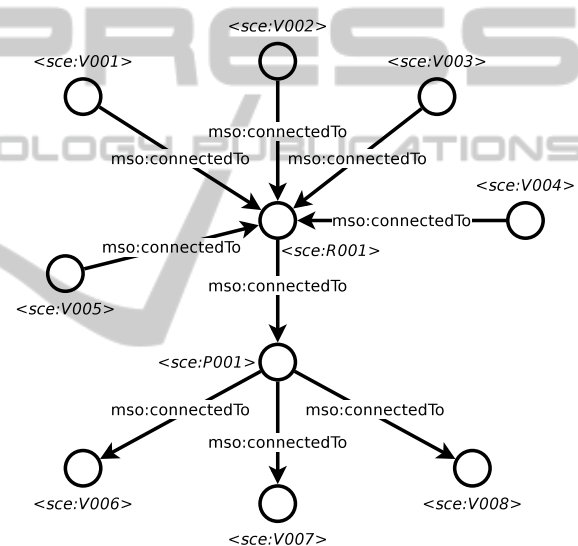Figure 3: Excerpt from the RDF representation of the plant structure.

Figure 4: Graph visualization of the RDF model.

the pump *R001* in the plant structure. All its relevant attributes are shown in the center of the UI, as can be seen in figure 5. They comprise the equipment's Name, plant ID, description, RFID tag and others. On the left side of the screen the list of equipments that can deliver liquids into the reactor, the valves *V001* to *V005*, can be seen. The right side contains the elements that are located downstream from the reactor. In this case, it is only the pump *P001*. Each element upstream and downstream from the current "center of the universe" has its title and its description shown to give the user a brief overview of the connected equipment.

Pressing the *Make Center* button of the pump *P001* brings *P001* to the middle of the UI and retrieves all of its attributes. There now is only one input item, namely *R001*. The new output equipments

Figure 5: Screenshot of the *Semantic Neighborhood Browser* accessing the flow of matter.

V006, *V007* and *V008* are listed on the right side.

5.4 Further Applications

The *Semantic Neighborhood Browser* was primarily developed to support device diagnosis tasks. However, it can be easily adapted to other navigation and information processing tasks with similar informational needs. It allows browsing of any reversible Linked Data relation and has therefore a broad range of possible applications. As a simple example one could follow physical or logical inputs and outputs of devices. This tracking covers different types of flows, for example matter flow, energy flow or information flow. However, because of its generic approach, it is suitable for all meshed networks. Also for non meshed connections the *Semantic Neighborhood Browser* can help to get a better overview of the connection structure. It is a good solution for navigating in predecessor and successor connections, in cause and effects connections or series of implications. Even the navigation through tree structures can be achieved.

6 DISCUSSION

6.1 Features

The developed *Semantic Neighborhood Browser* prototype provides the following features:

Generalization. The coupling of the UI to the data is very loose. The example data set can be easily replaced by other data accessible through a SPARQL endpoint.

Displayed Attributes. The item in the middle ("center of the universe") displays the attributes of an

entity depending on the ontology of the displayed data.

Ontology-based Neighborhood. The predicates used for the predecessor- and successor-relation are chosen at runtime depending on the ontology which is used for modeling the desired data. Thus, it is possible to switch to other predicates on the fly.

Back/Forward Navigation. Users can navigate by following the desired path through the reversible predicates and by using the forward/backward button.

Filtering. The items in the neighborhood can be filtered according to the displayed attributes with the power of regular expressions.

Sorting. By default, the predecessors and successors are sorted by title. But there is also the possibility to sort by other existing predicates in the ontology at runtime.

6.2 Challenges

When implementing the *Semantic Neighborhood Browser* we faced several issues concerning data integration, data availability and usability.

One bottleneck for integration of Linked Data is the transformation from other legacy systems to RDF. It requires additional effort, but since most data can be extracted in structured formats such as XML this conversion is not too difficult.

At the moment, our application needs a permanent connection to the remote SPARQL endpoint. This connectivity cannot always be ensured in industrial environments. A caching mechanism could resolve this problem in most cases. However, the evolving expansion of wireless technology (Industrial WLAN, UMTS) is probably going to mitigate this limitation in the future.

7 CONCLUSIONS & OUTLOOK

In this paper we presented a simple app that may be considered a first building block for an app orchestration approach on top of Linked Data. This app which is called *Semantic Neighborhood Browser* is good at presenting neighboring abstract or physical things in a Linked Data Cloud. The only precondition for its usage is that the objects in the cloud are reliably connected by a predicate that carries the semantics of being close.

A first expert evaluation of the demonstrator has revealed that the current implementation still needs

some fine tuning to be candidate for a fair usability study. First the app is missing graphical features like valve symbols which are essential in the domain of application, second the filter and sort functions which are essential in more complex settings have to be refined. These features are currently under development. For the next iteration a formal evaluation of usability and effectiveness is planned and will be conducted with engineering students on the one hand and engineers from partner companies on the other.

ACKNOWLEDGEMENTS

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